

## WHAT IS CLAIMED IS:

1. A method for controlling the entrained gas content of a liquid or slurry being flow-processed, the method comprising:

- a.) setting a quantitative target for the free gas content of said liquid or slurry;
- b.) continuously flowing said liquid or slurry and mixing an antifoam agent therewith;
- c.) determining the volume percentage of free gas,  $x\%$ , from the formula

$$x\% = \frac{V_s}{V_s + V}$$

wherein  $V_s$  is the volume of free gas under standard conditions and  $V$  is the gas-free volume of the liquid carrier component;

- e.) comparing the calculated free gas content to the target free gas content; and,
- f.) if the calculated free gas content is greater than the target free gas content, raising the amount of antifoam agent mixed in step b.).

2. The method of claim 1, wherein the liquid or slurry being flow-processed is a slurry of kaolin clay, calcium carbonate, titanium dioxide, or alumina trihydrate being supplied as a coating to a paper substrate.

3. The method of claim 1, wherein the liquid or slurry being flow-processed is ointment, cream, lotion, toothpaste, mayonnaise, ketchup, or lubricating grease being packaged into a retail container.

4. In an apparatus comprising a reservoir for process fluid, piping through which said process fluid may be pumped, and a deaerator unit, the improvement which comprises locating means for detecting the volume

percentage of free gas in said process fluid in working relationship to said deaerator unit.

5. The apparatus of claim 4, wherein a single such detection means is located downstream of said deaerator unit and wherein said apparatus further comprises an alarm capable of signaling the presence in said process fluid of a volume percentage of free gas higher than a pre-specified level.

6. The apparatus of claim 4, wherein two such detection means are located, respectively, upstream and downstream of said deaerator unit and wherein said apparatus further comprises a comparator capable of determining and indicating the magnitude of any difference in volume percentage of free gas in said process fluid upstream of and downstream of said deaerator unit.

7. A method of determining the amount of gas in a liquid which comprises subjecting a mixture of an incompressible liquid sample and a compressible gas to at least three different equilibrium pressure states, measuring the temperature and volume of the mixture at each of the at least three pressure states, determining the changes in volume of the mixture between at least two different pairs of pressure states, and calculating the amount of said gas in said liquid sample by using the equation

$$x\% = \frac{V_s}{V_s + V}$$

wherein V is the volume of the gas-free liquid in a sample chamber at ambient pressure and  $V_s$  is determined by the equation

$$V_s = \frac{\Delta V_1 T_s}{T} \frac{P_1^2}{P_s (P_2 - P_1)} + \frac{\Delta V_2 T_s}{T} \frac{P_3 (P_2 - P_1)}{P_s (P_3 - P_2)} + \frac{P_1 - P_s}{P_s} \left[ \frac{\Delta V_1 T_s}{T} - \frac{\Delta V_2 T_s}{T} \frac{P_3 (P_2 - P_1)}{P_1 (P_3 - P_2)} \right]$$

wherein  $P_1$ ,  $P_2$ , and  $P_3$  are three different equilibrium ambient pressures,  $P_s$  and  $T_s$  are standard pressure and temperature,  $\Delta V_1$  and  $\Delta V_2$  are the volume difference of the free air measured at an equilibrium state between  $P_1$  and  $P_2$  and  $P_2$  and  $P_3$ , respectively.

8. The method of claim 7, wherein said at least three equilibrium pressure states differ from one another at least to the extent that the three different volumes differ from one another by at least 0.1%.

9. The method of claim 7, wherein said at least three equilibrium pressure states differ from one another at least to the extent that three different apparent densities of said liquid differ from one another by at least 0.1%.

10. The method of claim 7, wherein said at least three pressure states differ from one another by at least 0.1 psi.

11. The method of claim 10, wherein said at least three pressure states differ from one another by at least 1 atmosphere.

12. The method of claim 7, wherein said determination of changes in volume is accomplished by measurement of volumes.

13. The method of claim 7, wherein said determination of changes in volume is accomplished by measurement of apparent densities.

14. An apparatus comprising: a reservoir for process fluid; piping through which said fluid may be pumped, said piping being under the control of a pressure regulator which is capable of setting at least three different pressures  $P_1$ ,  $P_2$ , and  $P_3$  in the apparatus; at least three fluid

control valves V1, V2, and V3; a pressure gauge; a temperature gauge; and a density gauge.

15. A method of obtaining data for use in determining amounts of air entrained or dissolved in a fluid, which comprises:  
providing an apparatus according to claim 14;  
collecting stabilized pressure, temperature, and density data at a first pressure level;  
collecting stabilized pressure, temperature, and density data at a second pressure level; and  
collecting stabilized pressure, temperature, and density data at a third pressure level.

16. A method for automatically controlling the output of a continuous process that requires mixing of a solid or liquid component with a liquid carrier component, the method comprising:  
a.) setting a quantitative target for weight-% of one or more solids and/or concentration of one or more liquids to the liquid carrier component;  
b.) continuously mixing said solids and/or liquids with the liquid carrier component;  
c.) filling a measurement chamber with the blended mixture and allowing it to come to equilibrium;  
d.) recording equilibrium temperature,  $T_1$ , the volume of the sample,  $V_1$ , and equilibrium pressure,  $P_1$ ;  
e.) increasing or decreasing the volume of the mixture in the sample chamber, allowing the fluid to come to equilibrium, and recording equilibrium temperature,  $T_2$ , sample volume,  $V_2$ , and equilibrium pressure,  $P_2$ ;  
f.) again, increasing or decreasing the volume of the mixture in the sample chamber, allowing the fluid to come to equilibrium, and recording

equilibrium temperature,  $T_3$ , sample volume,  $V_3$ , and equilibrium pressure,  $P_3$ ;

g.) determining the true density,  $\rho$ , by employing the formula

$$\rho = \frac{m}{V}$$

wherein the mass,  $m$ , is the mass of the liquid mixture sample, and, the gas-free volume of the liquid mixture,  $V$ , and the volume percentage of free air or other gas,  $x\%$ , are calculated from the formulas

$$V = V_{t1} - \left[ \Delta V_1 \frac{P_1}{(P_2 - P_1)} + \Delta V_2 \frac{P_3(P_2 - P_1)}{P_1(P_3 - P_2)} \right]$$

and,

$$x\% = \frac{V_s}{V_s + V}$$

wherein  $\Delta V_1$  is the volume difference of the free gas between  $P_1$  and  $P_2$ ,  $\Delta V_2$  is the volume difference of the free gas between  $P_2$  and  $P_3$ ,  $V_{t1}$  is the total volume of the liquid and entrained gas, and  $V_s$  is the volume of free air or other gas under standard conditions and is calculated from the formula

$$V_s = \frac{\Delta V_1 T_s}{T} \frac{P_1^2}{P_s(P_2 - P_1)} + \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_s(P_3 - P_2)} + \frac{P_1 - P_s}{P_s} \left[ \frac{\Delta V_1 T_s}{T} - \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_1(P_3 - P_2)} \right]$$

wherein these variables are provided by the data collected in steps d.-f.), and standard conditions refer to  $P = P_s = 1$  atm,  $T = T_s = 273$  K;

h.) calculating the weight-% of solids and/or the liquid concentration in the mixture with the equation

$$m = \frac{1}{\left( 1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_s)_i} \right)} - \frac{\rho_L}{\left( 1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_s)_i} \right)} \left( \frac{1}{\rho} \right)$$

wherein  $\rho_L$  is the density of the liquid carrier component,  $k_i$  is the Additive Volume Coefficient (AVC) for each solid or liquid,  $x_i$  is the weight-% dry for each solid or the concentration for each liquid,  $(\rho_s)_i$  is the density of each solid or liquid, and  $\rho$  is the true density of the mixture;

- i.) comparing the calculated weight-% solids or concentration to the target weight-% solids or concentration; and,
- j.) if the calculated weight-% solids or concentration is greater or less than the target weight-% solids or concentration, lowering or raising the amount of solids or liquids mixed in step b.).

17. A method for automatically controlling the output of a continuous process that requires mixing of a solid or liquid component with a liquid carrier component, the method comprising:

- a.) setting a quantitative target for weight-% of one or more solids and/or concentration of one or more liquids to the liquid carrier component;
- b.) continuously mixing said solids and/or liquids with the liquid carrier component;
- c.) diverting a fluid sample from the main piping system into the sample measurement chamber and allowing the sample to come to equilibrium;
- d.) recording equilibrium temperature,  $T_1$ , equilibrium density,  $\rho_1$ , and equilibrium pressure,  $P_1$ ;
- e.) adjusting the pressure of the fluid in the sample chamber, allowing the fluid to come to equilibrium, and recording equilibrium temperature,  $T_2$ , equilibrium density,  $\rho_2$ , and equilibrium pressure,  $P_2$ ;
- f.) again, adjusting the pressure of the fluid in the sample chamber, allowing the fluid to come to equilibrium, and recording equilibrium temperature,  $T_3$ , equilibrium density,  $\rho_3$ , and equilibrium pressure,  $P_3$ ;
- g.) determining the true density,  $\rho$ , by employing the formula

$$\rho = \frac{1}{V}$$

wherein the volume,  $V$ , is calculated from the formula

$$V = \frac{1}{\rho_1} - \left[ \left( \frac{1}{\rho_1} - \frac{1}{\rho_2} \right) \frac{P_1}{(P_2 - P_1)} + \left( \frac{1}{\rho_2} - \frac{1}{\rho_3} \right) \frac{P_3(P_2 - P_1)}{P_1(P_3 - P_2)} \right]$$

wherein these variables are provided by the data collected in steps d.-f.);  
 h.) calculating the weight-% of solids and/or the liquid concentration in the mixture with the equation

$$m = \frac{1}{\left(1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_s)_i}\right)} - \frac{\rho_L}{\left(1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_s)_i}\right)} \left(\frac{1}{\rho}\right)$$

wherein  $\rho_L$  is the density of the liquid carrier component,  $k_i$  is the Additive Volume Coefficient (AVC) for each solid or liquid,  $x_i$  is the weight-% dry for each solid or the concentration for each liquid,  $(\rho_s)_i$  is the density of each solid or liquid, and  $\rho$  is the true density of the mixture;

i.) comparing the calculated weight-% solids or concentration to the target weight-% solids or concentration; and,  
 j.) if the calculated weight-% solids or concentration is greater or less than the target weight-% solids or concentration, lowering or raising the amount of solids or liquids mixed in step b.).

18. The method of one of claims 16 or 17 for continuously coating a substrate, which method comprises:

- a.) setting a quantitative target for weight-% of one or more solids to be coated onto a substrate;
- b.) continuously applying the solids to the substrate via a carrier fluid;
- c.) measuring the apparent density of the slurry;
- d.) determining the true density of the slurry;
- e.) calculating the weight-% of solids in the slurry in the manner recited in claim 16 or in the manner recited in claim 17;
- f.) comparing the calculated weight-% solids to the target weight-% solids; and,
- g.) if the calculated weight-% is greater or less than the target weight-%, lowering or raising the amount of solids applied in step b.).

19. The method of claim 18, in which the substrate is a paper web and the solids component comprises kaolin clay, calcium carbonate, titanium dioxide, or alumina trihydrate.

20. The method of one of claims 16 or 17 for controlling the output of a continuous process for preparing a syrup, which method comprises:

a.) setting a quantitative target for a concentration of one or more carbohydrates and/or carbohydrate-containing liquids to be blended into a syrup;

b.) continuously supplying the carbohydrate and/or carbohydrate-containing liquid and a dilution liquid to a vessel and mixing said liquids to form a slurry;

c.) measuring the apparent density of the slurry;

d.) determining the true density of the slurry;

e.) converting this true density to the calculated carbohydrate concentration;

f.) comparing the calculated carbohydrate concentration to the target carbohydrate concentration; and,

g.) if the calculated carbohydrate concentration is greater or less than the target carbohydrate concentration, lowering or raising the amount of carbohydrates and/or volume of carbohydrate-containing liquids supplied in step b.).

21. The method of claim 20, in which carbohydrates comprising sucrose and carbohydrate-containing liquids comprising corn syrup and high fructose corn syrup are mixed with a dilution liquid comprising water.

22. A method for controlling the output of a continuous process for preparing a carbonated beverage, which method comprises:



a.) setting a quantitative target for a concentration of carbon dioxide to be blended into an aqueous medium;

b.) continuously supplying carbon dioxide to the aqueous medium in a vessel and mixing those components to form a carbonated aqueous medium in the vessel at a preset "bottling" pressure  $P_0$ , wherein  $P_0$  is the produced "bottling" pressure inside a sealed carbonated beverage container, at which pressure all of the free carbon dioxide is dissolved into the aqueous medium;

c.) diverting a carbonated aqueous medium sample from the vessel into a sample measurement chamber at the same "bottling" pressure  $P_0$ ;

d.) reducing the aqueous medium pressure from  $P_0$  to  $P_1$  allowing the dissolved carbon dioxide to start to be released back to the aqueous medium in a free-bubble form;

e.) reducing the aqueous medium pressure further from  $P_1$  to  $P_2$  allowing a sufficient amount of the dissolved carbon dioxide to be released back to the aqueous medium in a free-bubble form;

f.) measuring the change in volume of the carbon dioxide liquid mixture at an equilibrium state between  $P_1$  and  $P_2$ ;

g.) reducing the aqueous medium pressure further from  $P_2$  to  $P_3$  allowing more dissolved carbon dioxide to be released back to the aqueous medium in a free-bubble form;

h.) measuring the change in volume of the carbon dioxide liquid mixture at an equilibrium state between  $P_2$  and  $P_3$ ;

i.) determining the volume of free carbon dioxide,  $V_s$ , in the carbonated aqueous medium at the standard condition using the equation

$$V_s = \frac{\Delta V_1 T_s}{T} \frac{P_1^2}{P_s(P_2 - P_1)} + \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_s(P_3 - P_2)} + \frac{P_1 - P_s}{P_s} \left[ \frac{\Delta V_1 T_s}{T} - \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_1(P_3 - P_2)} \right]$$

wherein  $P_1$ ,  $P_2$ , and  $P_3$  are three different equilibrium ambient pressures,  $P_s$  and  $T_s$  are standard pressure and temperature,  $\Delta V_1$  and  $\Delta V_2$  are the volume

difference of the free carbon dioxide measured at an equilibrium state between  $P_1$  and  $P_2$  and  $P_2$  and  $P_3$ , respectively;

j.) calculating the carbon dioxide concentration using the equation

$$x^0\% = \frac{V_s}{V_s + V}$$

wherein  $V_s$  is the volume of free carbon dioxide determined in i.) and  $V$  is the volume of carbonated aqueous medium in the sample chamber at a preset "bottling" pressure  $P_0$  upon which no free bubble should present;

k.) comparing the calculated carbon dioxide concentration to the target carbon dioxide concentration; and,

l.) if the calculated carbon dioxide concentration is greater or less than the target carbon dioxide concentration, lowering or raising the volume of carbon dioxide supplied in step b.).

23. The method of claim 22, in which the carbonated beverage is selected from the group consisting of soft drinks, beer, and carbonated wines.

24. A method for determining the concentration of a solid or liquid component in a liquid carrier component, which comprises:

- a.) measuring the apparent density of the mixture;
- b.) determining therefrom the true density of the mixture; and
- c.) calculating the weight-% of solids in the slurry in the manner recited in one of claims 16 or 17.

25. A method for determining the true density of a solid or liquid component in a liquid carrier component, which comprises:

- a.) measuring the apparent density of the mixture; and
- b.) determining therefrom the true density of the mixture.

26. A method for determining the entrained air content of a liquid component, which comprises:

- a.) measuring the apparent air content of the liquid at a variety of pressures; and
- b.) determining therefrom the true entrained air content of the liquid.

27. A method of characterizing a liquid by determining its entrained air content, which comprises calculating the volume percentage of free air, x%, in the liquid using the equation

$$x\% = \frac{V_s}{V_s + V}$$

wherein V is the volume of the gas-free liquid in a sample chamber at ambient pressure and  $V_s$  is determined by the equation

$$V_s = \frac{\Delta V_1 T_s}{T} \frac{P_1^2}{P_s(P_2 - P_1)} + \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_s(P_3 - P_2)} + \frac{P_1 - P_s}{P_s} \left[ \frac{\Delta V_1 T_s}{T} - \frac{\Delta V_2 T_s}{T} \frac{P_3(P_2 - P_1)}{P_1(P_3 - P_2)} \right]$$

wherein  $P_1$ ,  $P_2$ , and  $P_3$  are three different equilibrium ambient pressures,  $P_s$  and  $T_s$  are standard pressure and temperature,  $\Delta V_1$  and  $\Delta V_2$  are the volume difference of the free air measured at an equilibrium state between  $P_1$  and  $P_2$  and  $P_2$  and  $P_3$ , respectively.

28. A method of identifying a sample of unknown constitution which comprises comparing its entrained air content with a collection of entrained air contents, for a variety of known compounds, determined according to the method of claim 27.

29. A method of identifying a sample of unknown constitution which comprises comparing its true density with a collection of true densities, for a variety of known compounds, determined by use of the relationship  $\rho = \frac{m}{V}$ .

30. A method of identifying a sample of unknown constitution which comprises comparing its % solids with a collection of % solids, for a variety of known compounds, determined according to the relationship

$$m = \frac{1}{\left(1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_S)_i}\right)} - \frac{\rho_L}{\left(1 - \rho_L \sum_{i=1}^n \frac{k_i x_i}{(\rho_S)_i}\right)} \left(\frac{1}{\rho}\right).$$